Impact of experimental domestic water buffalo *Bubalus bubalis* grazing on waterhole dynamics in north-eastern Cambodia

Jonathan C. EAMES[1,*], EANG Samnang[1], Robin LOVERIDGE[1,2] & Thomas N.E. GRAY[3]

[1] BirdLife International Cambodia Programme, 32A, Street 494, Sangkat Phsar Daeum, Thkov, Chamkarmon, Phnom Penh, Cambodia.

[2] Sustainability Research Institute, University of York, Heslington, York, YO10 5DD, UK.

[3] Wildlife Alliance, 1441 Broadway, 5th Floor New York, NY 10018, USA.

* Corresponding author. Email Jonathan.Eames@birdlife.org

Paper submitted 19 September 2018, revised manuscript accepted 13 December 2018.

មូលន័យសង្ខេប

ព្រៃរបោះនៅភាគខាងជើង និងខាងកើតនៃប្រទេសកម្ពុជាមានសារៈសំខាន់ខ្លាំងជាសាកល ដែលមិនអាចជំនួសបានសម្រាប់ការអភិរក្សជីវចម្រុះ។ ការថយចុះយ៉ាងច្រើននូវជីវម៉ាសនៃសត្វតិណាសីនៅក្នុងតំបន់ ដោយសារការបរបាញ់ពពួកសត្វទំពាអៀង និងការផ្លាស់ប្តូររបៀបនៃការចិញ្ចឹមសត្វ ទំនងជាបានប៉ះពាល់ដល់រចនាសម្ព័ន្ធនៃព្រៃឈើទាំងនោះ។ ផលប៉ះពាល់នោះប្រហែលជាសមហេតុផលនៅតាមត្រពាំងទឹកតាមរដូវ ដែលជាកន្លែងគេគិតថា ការស៊ីស្មៅដោយសត្វទំពាអៀងគឺ មានសារៈសំខាន់ក្នុងការរក្សាឲ្យមាននានាភាពនៅតាមទីជម្រកតូចៗ ដែលរស់នៅដោយសត្វស្លាបទឹកខ្លួនធំ ដែលមានការគំរាមកំហែងជាសកល ដូចជាសត្វស្លាបកំពុងរងគ្រោះ ត្រយ៉ងយក្ស (*Thaumatibis gigantea*) និងត្រយ៉ងចង្កំកស (*Pseudibis davisoni*)។ ដើម្បីធ្វើការផ្ទៀងផ្ទាត់សម្មតិកម្មនេះ យើងបានធ្វើពិសោធន៍ដោយឱ្យមានការស៊ីស្មៅនៅត្រពាំងទឹកចំនួន៩ក្នុងតំបន់ដែនជម្រកសត្វព្រៃសៀមប៉ាង ភាគឦសាន្តនៃប្រទេសកម្ពុជាដោយសត្វក្របីស្រុកពីរក្រុមនៅអំឡុងបីរដូវប្រាំង រួចធ្វើការប្រៀបធៀបទីជម្រកនៃត្រពាំងទាំងនោះជាមួយនឹងត្រពាំងទឹកគំរូ (control waterholes) ចំនួន១០។ នៅអំឡុងរដូវប្រាំង លក្ខណៈរូបរបស់ត្រពាំងទាំងអស់បានប្រែប្រួលជាប្រចាំ និងអាចព្យាករបាន ទោះបីវាជាត្រពាំងទឹកគំរូឬជាត្រពាំងទឹកបានស៊ីដោយសត្វក្របីក៏ដោយ។ យើងបានរកឃើញភាពខុសគ្នាជាប្រចាំមួយចំនួន រវាងត្រពាំងទឹកគំរូ និងត្រពាំងទឹកដែលក្របីបានស៊ីស្មៅ ទោះបីជាមានភស្តុតាងមួយចំនួនបង្ហាញថា ត្រពាំងទឹកដែលមានសត្វក្របីស៊ីស្មៅ អាចរក្សាទឹក និងមានភក់សើមបានយូរនៅរដូវប្រាំង ដែលលក្ខខណ្ឌបែបនេះគឺជាជម្រកដ៏សំខាន់របស់សត្វត្រយ៉ង។ ទោះបីជាយ៉ាងណាក៏ដោយ ផ្អែកលើទិន្នន័យនេះ យើងមិនទាន់អាចឈានដល់ការសន្និដ្ឋានជាចុងក្រោយមួយឡើយ អំពីឥទ្ធិពលនៃសកម្មភាពរបស់សត្វក្របីទៅលើរចនាសម្ព័ន្ធរបស់ត្រពាំងទឹកនៅក្នុងព្រៃរបោះនៃប្រទេសកម្ពុជា។ ករណីនេះអាចកើតឡើងដោយសារ ចំនួនសត្វក្របីដែលយើងកំណត់ គឺអាចមិនទាន់គ្រប់គ្រាន់ ឬអាចមិនទាន់មានឥទ្ធិពលខ្លាំងដល់ការពិសោធន៍នេះ។

Abstract

The open deciduous dipterocarp forests of northern and eastern Cambodia are globally irreplaceable for biodiversity conservation. The substantial declines occurring in herbivore biomass within the eco-region due to hunting of wild ungulates and changing animal husbandry patterns are likely impacting the structure of these forests. These impacts may be particularly pertinent at seasonal waterholes where it is hypothesized that grazing by ungulates is important for maintaining micro-habitat diversity utilized by globally threatened large water birds such as the Critically Endangered giant ibis *Thaumatibis gigantea* and white-shouldered ibis *Pseudibis davisoni*. To test this, we experimentally grazed eight waterholes in the globally significant Siem Pang Wildlife Sanctuary in northeastern Cambodia with two herds

---

CITATION: Eames, J.C., Eang S., Loveridge, R. & Gray, T.N.E. (2018) Impact of experimental domestic water buffalo *Bubalus bubalis* grazing on waterhole dynamics in north-eastern Cambodia. *Cambodian Journal of Natural History*, **2018**, 101–109.

of domestic water buffaloes over three dry seasons and compared their micro-habitats with 10 control waterholes. During the dry season, the physical characteristics of all waterholes changed predictably and consistently, irrespective of whether they were controls or grazed by our buffaloes. We found few consistent differences between control waterholes and those grazed by buffaloes, although there was some evidence that grazed waterholes retained water and saturated mud, the latter a critical habitat for ibis, for longer into the dry season. However, we could not arrive at definitive conclusions about the effect of water buffalo activity on waterhole structure in deciduous dipterocarp forests in Cambodia from our data and it is possible that the densities of buffaloes we employed were not sufficient to significantly or detectably influence this.

Keywords

Conservation management, dry forest, ecosystem services, re-wilding, wild cattle.

Introduction

Large herbivores play a critical role in ecosystem functioning and the significant declines in herbivore populations globally are likely to have had major impacts on many aspects of ecosystem structure and thus biodiversity (Ripple *et al.*, 2015). The deciduous dipterocarp forests (DDF) of insular Southeast Asia are a prime example of an ecosystem whose functioning is likely to have been significantly impacted by large herbivore declines (Miles *et al.*, 2006; Tordoff *et al.*, 2012). These savannah forests were historically described as one of the great game lands of the world and supported a unique assemblage of four species of wild cattle (banteng *Bos javanicus*, gaur *B. gaurus*, kouprey *B. sauvelli*, wild water buffalo *Bubulus arnee*), combined with abundant deer and widespread Asian elephant *Elephas maximus*. As such, herbivory, trampling and wallowing by herbivores, notably Asian elephant and wild water buffalo, likely played a key role in structuring these forests and creating suitable habitat mosaics including waterholes for water birds.

The largest extent of DDF remaining globally occurs in Cambodia in a series of protected areas in the northern and eastern provinces of Mondulkiri, Stung Treng, Rattanakari and Preah Vihear. These are globally irreplaceable for conservation of DDF and its characteristic biodiversity (Gray *et al.*, 2012; Tordoff *et al.*, 2012). Despite declines in their mammalian megafauna, these forests still support important populations of globally threatened birds including the giant ibis *Thaumatibis gigantea* and white-shouldered ibis *Pseudibis davisoni* (both Critically Endangered), greater adjutant *Leptoptilos dubius* (Endangered), lesser adjutant *Leptoptilos javanica* and Asian woollyneck *Ciconia episcopus* (both Vulnerable) and three species of vultures (all Critically Endangered) (Gray *et al.*, 2014; Ty *et al.*, 2016). White-shouldered and giant ibises are largely DDF specialists, with the former a near-endemic and the latter now endemic to DDF in the Mekong basin, and both are dependent on seasonal waterholes within the forest for feeding (Keo, 2008). During the dry season, dried mud and short vegetation at waterholes have been identified as essential foraging habitat for the white-shouldered ibis (Wright *et al.*, 2010), whereas the giant ibis prefers saturated mud (Wright *et al.*, 2012). In eastern Cambodia, Pin *et al.* (2018) found that water depth and size of the open area of low vegetation surrounding waterholes were positively correlated with use by threatened water birds.

It has been suggested that wallowing and grazing by domestic water buffaloes *Bubalus bubalis* may play an important role in maintaining the ecological integrity of waterholes in the absence of wild ungulates such as wild water buffaloes and Asian elephants. Due to agricultural modernisation, buffalo ownership in many areas of DDF is decreasing. For example, in the Siem Pang and Siem Pang Khan Lech Wildlife Sanctuaries (hereafter collectively referred to as Western Siem Pang Wildlife Sanctuary), which support the largest known population of white-shouldered ibis globally, 80% of buffalo owners have expressed a desire to replace buffaloes with hand-drawn tractors in the near future due to problems with livestock disease (BirdLife International Cambodia Programme, unpublished data). Wright *et al.* (2013) hypothesised that the absence of domestic buffaloes from this site would increase sedimentation and vegetation at waterholes and reduce their suitability for species such as the white-shouldered ibis. As such, maintaining extensive rearing of domestic water buffaloes could be important for conservation of the ibis.

The aim of our study was to examine the impact of targeted stocking and grazing of domestic water buffaloes on waterholes in Western Siem Pang Wildlife Sanctuary, north-eastern Cambodia. We hypothesised that increased levels of grazing by domestic water buffaloes would increase the extent of low vegetation and dry mud preferred by white-shouldered ibises for foraging during their dry season breeding period and that such micro-habitats would be more extensive in experimental waterholes receiving managed grazing by domestic water buffaloes than at control waterholes.

Methods

Study area

Our study was conducted within Siem Pang Wildlife Sanctuary (66,932 ha) and Siem Pang Khang Lech Wildlife Sanctuary (65,389 ha) (Fig. 1). The latter was added to Cambodia's protected area system in May 2016 (Souter *et al.,* 2016) and the two sites are now treated as a single management unit. These are collectively referred to as Western Siem Pang Wildlife Sanctuary in this paper. Treated as such, Western Siem Pang Wildlife Sanctuary contains the largest known subpopulation of white-shouldered ibises globally, with a minimum of 346 birds (Wright *et al.,* 2013), together with a breeding population of 50 giant ibises (Ty *et al.,* 2016) and Cambodia's largest remaining population of vultures which comprise breeding red-headed vultures *Sacrogyps calvus*, white-rumped vultures *Gyps bengalensis* and slender-billed vultures *G. tenuirostris*. Despite a significant (ca. 50–100 individuals) population of Eld's deer *Rucervus eldii* (a wallowing species), the landscape supports few mammals larger than wild pigs *Sus scrofa* (also a wallowing species), with Asian elephants extirpated in Siem Pang Kang Lech Wildlife Sanctuary and very low numbers of banteng and gaur remaining.

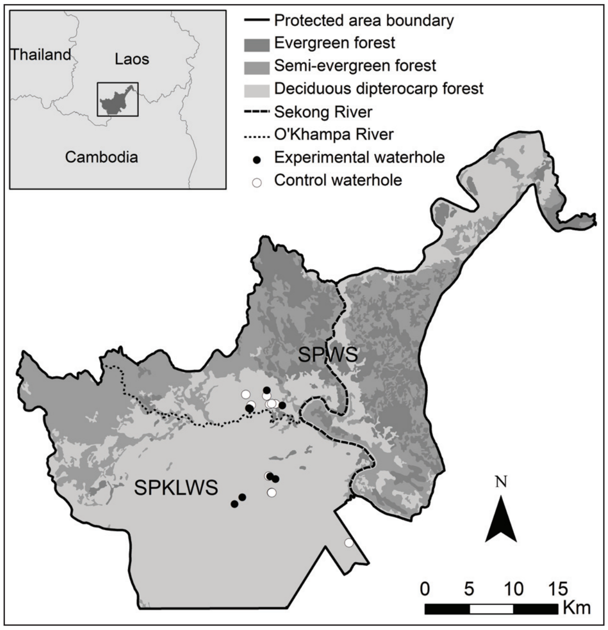

Fig. 1 Location of experimental and control waterholes in Siem Pang Kang Lech Wildlife Sanctuary (SPKLWS) and Siem Pang Wildlife Sanctuary (SPWS), northeastern Cambodia (collectively referred to as Western Siem Pang Wildlife Sanctuary in this study).

The landscape of Western Siem Pang Wildlife Sanctuary comprises DDF, which mainly occurs west of the Sekong River, and semi-evergreen forest to the north and east of the Sekong River (Fig. 1). The Sekong River and its associated riverine forests bissect the protected area. Waterholes (*trapeang* in Khmer) ranging in size from 0.001–3.4 ha occur throughout the DDF and strongly seasonal rainfall creates spatiotemporal variation in water levels and substrate moisture (Wright *et al.,* 2010). The rainy season occurs in May–October with maximal monthly rainfall (mean 333 mm) in September. The dry season occurs in November–April, with minimal monthly rainfall (mean 0.9 mm) in January (Thuon & Chambers, 2006).

Waterhole manipulation

We selected 18 seasonal waterholes in Western Seam Pang and allocated these to two types: i) control waterholes (n = 10); ii) experimental waterholes (n = 8) (Fig. 1). The waterholes were not randomly selected because clusters relatively short distances apart were preferable to allow us to move our buffalo herds safely with minimal stress to the animals. As such, the waterholes might not have been independent with respect to ecological processes affecting the study site, although we anticipated that factors such as rainfall would influence all waterholes to the same extent. Distances between waterholes varied from 20 m to 1,343 m. The mean dimensions of the waterholes were 46 m x 64.4 m, with an average area of 2,967 m^2. Differences in the dimensions of control and experimental waterholes were not significant (Appendix 1; One-Way ANOVA on normally distributed data: $F = 0.33$, $p = 0.72$).

BirdLife International purchased 24 domestic water buffaloes within Seam Pang District in 2014 on the assumption that locally procured stock would be adapted to DDF. This number grew to 28 because many of the females were pregnant when purchased and calved during the experiment. Our initial plan was to establish two herds of domestic water buffalo: i) a large herd comprising 16 individuals; and ii) a small herd comprising eight individuals. Four experimental waterholes were to be grazed by the large herd for seven days per waterhole/month, and four more were to be grazed by the small herd for seven days per waterhole/month on a continuous rotation. However, 14 of the buffaloes died during a drought caused by the 2016 El Niño event. As a consequence, four waterholes were grazed by between 8–16 buffaloes (depending on study year) for seven days each month (high intensity treatment) and four were grazed by eight buffaloes for seven days per month (low intensity treatment). The decision to deploy these grazing intensities was subjectively made. Prior to the experiment, the waterholes selected were judged to have sufficient vegetation for the chosen grazing intensity for the study duration. We anticipated our grazing intensities might mimic a natural grazing regime, but had no baseline to guide us due to the lack of literature on natural grazing levels in DDF.

When grazing at waterholes, buffalo herds were restricted to less than 20 m from the waterhole edge with electrical fencing (solar-powered, single-strand white tape) (Fig. 2). Grazing at waterholes only occurred during the dry season (November through February) and outside of this period, the buffalo were kept in electric-fenced areas nearby or at the closest village. The eight experimental waterholes were grazed by buffalo for three successive dry seasons: 2014–15, 2015–16 and 2016–17.

Waterhole microhabitats

The extent of different microhabitats was recorded at all 18 waterholes at approximately monthly intervals during each dry season. In the 2014–15 dry season, waterholes were visited between December and April four times (excluding January 2015). During the 2015–16 and 2016–17 dry seasons, each waterhole was visited monthly between November and April for a total of six visits per waterhole. Microhabitats recorded were based on distinctions in moisture level and were those identified as being important for ibis foraging by Wright *et al.* (2012). These comprised pools of water and saturated, wet or dry substrates (Fig. 3). Mud was classified in increasing order of dryness as saturated, wet, or dry based on criteria in Wright *et al.* (2012). During each visit the extent of each microhabitat at waterholes was sketched following Wright *et al.* (2012). We then digitized the sketch maps and calculated the area of each microhabitat in ArcGIS 9.3 (ESRI, 2015). Because the size of waterholes was variable, although consistent between treatments (Appendix 1), we converted these area measurements into a percentage of the total waterhole area for analysis. Vegetation height at each waterhole was calculated as the mean height of vegetation measured at four randomly selected points (Fig. 4).

A protocol was developed to monitor waterhole use by white-shouldered ibises, giant ibises and free-ranging domestic water buffaloes. Two observers visited each waterhole twice a month during the 2014–15, 2015–16 and 2016–17 dry seasons. These visits were separate to trips made to measure microhabitats at each waterhole. The date of the visits was random but one occurred in

Fig. 3 An experimental waterhole showing the full range of substrates.

Fig. 2 Domestic water buffalo at an experimental waterhole. The electric fence can be seen in the background.

Fig. 4 An experimental waterhole showing the full range of substrates and vegetation.

the first two weeks of each month and the second in the second two weeks of each month. Each visit lasted up to 20 minutes and occurred between 0700–1000 hrs or 1400–1700 hrs.

Data analysis

We calculated mean (± SD) percentage cover of microhabitats and mean vegetation height at every waterhole for each survey month (i.e., November until April) during the study period. To estimate the effect of buffalo grazing on the microhabitat structure of waterholes, we compared the microhabitat data from the final study month (April 2017) across the 18 waterholes using a multivariate analysis of variance (MANOVA), with treatment type as the dependent variable and microhabitat as the response variable. This analysis was conducted in R (vers. 3.5.1; R Core Team, 2018) using the *dplyr* package. Prior to inclusion in the MANOVA, microhabitat variables were tested for normality using the Shapiro-Wilk normality test in the *mvnormtest* package. The same analysis was done on microhabitat data for waterholes at the beginning of the study (November/December 2014).

Results

A total of 334 survey visits were conducted to measure microhabitats at the 18 waterholes between November 2014 and April 2017. During this period, the physical characteristics of all waterholes changed predictably and consistently in the dry season, largely irrespective of treatment type (Fig. 5). More specifically, the area of water at each waterhole declined precipitously (Fig. 5A), the extent of saturated mud declined (Fig. 5B), the amount of wet mud increased before declining in January (Fig. 5C), the extent of dry mud increased (before plateauing at > 70% of waterhole area: Fig. 5D), whereas mean vegetation height declined (Fig. 5E).

While there were few clear or consistent differences in waterholes between the three treatments (i.e., control, high intensity grazing and low intensity grazing), grazed waterholes retained water and saturated mud for longer in the dry season compared to controls (Fig. 5A–B; Appendix 2). The Shapiro-Wilk normality test on micro-

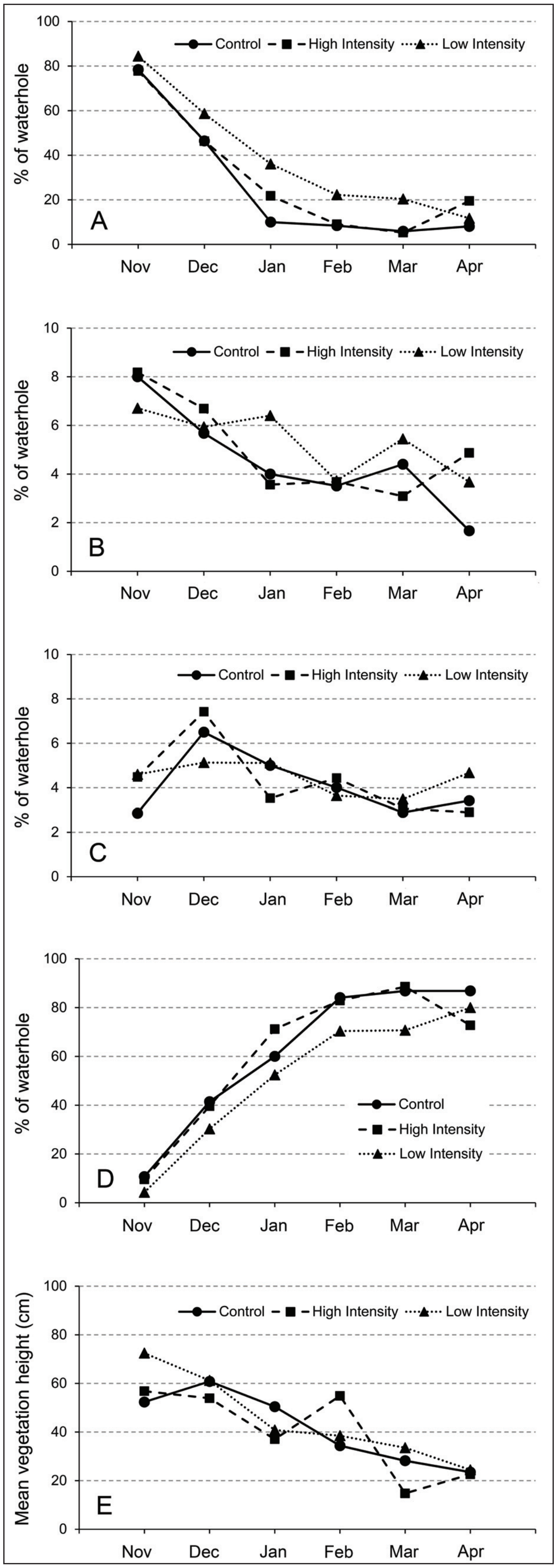

Fig. 5 (right) Changes in the microhabitat composition of waterholes between the three treatments in Western Siem Pang from November to April: A) % of water, B) % of saturated mud, C) % of wet mud, D) % of dry mud, E) mean vegetation height. The figure shows mean monthly values for each microhabitat across the three study dry seasons.

habitat data for waterholes during the final study month (Appendix 3) indicated that three variables (water area, dry mud area and mean vegetation height) were normally distributed ($W > 0.72$, $p > 0.05$). These were included as response variables in the MANOVA which indicated no significant differences in microhabitat structure between the three treatments ($F = 1.55$, $p = 0.2$; Appendix 4). A similar analysis on the same, normally distributed variables during the first project month (Appendix 3) also found no significant differences in microhabitat structure between treatments ($F = 1.45$; $p = 0.23$).

The giant ibis was not detected during the study period. However, white-shouldered ibises were detected on 56 survey visits. While the latter appeared to be detected more frequently at waterholes grazed by our buffalo herds (Table 1), it is difficult to interpret this finding as the waterholes were non-randomly allocated between treatments. Free-ranging domestic water buffaloes were detected on 34 survey visits with a mean herd size of 11 individuals (Appendix 5). Control waterholes appeared to be visited by domestic livestock less frequently than experimental waterholes (Appendix 5).

Table 1 Number and percentage of visits to waterholes in which white-shouldered ibis (WSI) were observed.

Treatments	No. of visits with WSI detections	% of visits with WSI detections
Control (*n*=10 waterholes)	23	7.9
High intensity grazing (*n*=4)	15	13.4
Low intensity grazing (*n*=4)	18	16.1

Discussion

Seasonal waterholes are critical for maintaining the conservation value of DDF in Indochina. This value includes providing foraging habitat for globally threatened water birds such as the giant ibis and white-shouldered ibis and water for large mammals including banteng and Eld's deer (Gray *et al.,* 2015). Our study demonstrates that the microhabitat characteristics of waterholes changes extensively during the dry season in DDF. This environmental change clearly influences the natural history of the landscape's fauna. For instance, Wright *et al.* (2012) demonstrated that the dry season breeding period of the white-shouldered ibis is linked to the drying of waterholes, which increases access to resource-rich dry mud for foraging. In contrast, the giant ibis (which breeds in the wet season) preferentially forages in wet and saturated mud, which our results show are increasingly scarce habitats as the dry season progresses.

Despite the hypothesized influence of large ungulates on the microhabitat structure of waterholes, we failed to find significant physical differences between experimentally grazed waterholes and controls. Seasonality (e.g., month in dry season) was a much stronger predictor of waterhole dynamics than our experimental grazing. However, the experimentally grazed waterholes did appear to hold water and saturated mud, key habitats for wildlife in Cambodian DDF (Wright *et al.,* 2012; Pin *et al.,* 2018), for longer into the dry season than controls (Fig. 5). We analysed the percentage cover of each micro-habitat rather than their absolute area. While the total area of a substrate may be an important foraging cue for threatened water birds, given the lack of significant differences in the waterhole size between treatments, we regarded percentage cover as suitable for indicating microhabitat availability for large water birds and the impact of grazing on waterhole structure.

There may be several reasons why our experimental grazing did not cause more substantial changes to the microhabitat structure of waterholes. First, numbers of buffaloes in our experimental herds (8–16) were low and approximately half of what we had planned due to deaths that occurred during the study. Compared with historical densities of ungulates in Southeast Asian dry forests (Wharton, 1968; Eisenberg & Seidensticker, 1976), the density of individuals and biomass of grazers at our experimental waterholes were extremely low. Second, free-ranging domestic water buffalo were observed at control waterholes on 10 visits, with a mean group size of 13.6 buffalo (range 2–55), although free-ranging domestic buffaloes were detected more frequently at the experimental waterholes. For a more effective experiment, we should have maintained larger buffalo herds and fenced control waterholes to prevent grazing and wallowing by free-ranging domestic animals, although this would have been logistically difficult to implement. Restricting access to control waterholes for three dry seasons might also have affected local populations of Eld's deer, other wild large mammals and domestic livestock. However, it ultimately seems likely that levels of grazing between our three treatments did not differ significantly and that our experimental waterholes did not experience sufficient grazing, trampling or wallowing to cause major changes in their microhabitat structure.

Given these issues, we cannot make definitive conclusions on the impact of water buffalo activity on waterhole function in Cambodian DDF. Excluding all grazing animals from waterholes over multiple years may provide greater insights into the role that large ungulates play in structuring microhabitats used by threatened large water birds in the landscape. As noted above however, such an exclusion could impact wild ungulate populations and should therefore be carefully considered prior to implementation. Our results suggest that re-wilding efforts in DDF will require larger numbers of herbivores than we employed to achievable measurable and ecologically significant results. Given existing and ambitious plans for re-wilding Indochinese DDF, including the reintroduction of tigers *Panthera tigris*, which may require stocking of domestic water buffaloes to recover ungulate biomass and provide sufficient prey (Gray *et al.*, 2018; WWF Cambodia, pers. comm. 2018), understanding the impact of herbivores on waterholes is important. As such, the extent to which water buffalo numbers affect waterhole dynamics and microhabitats used by Cambodia's globally significant populations of large water birds should remain a key research subject.

Acknowledgements

This study was undertaken by BirdLife International and funded by the Critical Ecosystem Partnership Fund (CEPF). The CEPF is a joint programme of l'Agence Française de Development, Conservation International, the European Union, the Global Environment Facility, the Government of Japan, the MacArthur Foundation and the World Bank and aims to conserve biodiversity and sustain livelihoods by providing support for biodiversity conservation measures and capacity building for civil society organisations. BirdLife International works in Western Siem Pang Wildlife Sanctuary through the full support of the Royal Government of Cambodia, particularly the Ministry of Environment, and we thank Eng Phirong and the staff of the Stung Treng Provincial Department of Environment.

References

Eisenberg, J.F. & Seidensticker, J. (1976) Ungulates in southern Asia: a consideration of biomass estimates for selected habitats. *Biological Conservation*, **10**, 293–308.

ESRI—Environmental Systems Research Institute (2015) *ArcGIS, Release 9.3*. Environmental Systems Research Institute, California, USA.

Gray, T.N.E., Prum S., Pin C. & Phan C. (2012) Distance sampling reveals Cambodia's Eastern Plains Landscape supports the largest global population of the Endangered banteng *Bos javanicus*. *Oryx*, **46**, 563–566.

Gray, T.N.E, Pollard, E.H., Evans, T.D., Goes, F., Grindley, M., Keo O., Nielsen, P., Sambovannak O., Phan C. & Sophoan S. (2014) Birds of Mondulkiri, Cambodia: distribution, status and conservation. *Forktail*, **30**, 66–78.

Gray, T.N.E, McShea, W.J., Koehncke, A., Sovanna P. and Wright, M. (2015) Artificial deepening of seasonal waterholes in eastern Cambodia: impact on water retention and use by large ungulates and waterbirds. *Journal of Threatened Taxa*, **7**, 189–7195.

Gray, T.N.E, Baltzer, M.C., Gopal, R. & Seng T. (2018) Not yet an obituary for Cambodia's tigers. *Cambodian Journal of Natural History*, **2018**, 137–139.

Pin C., Ngoprasert, D., Gray, T.N.E., Savini, T., Crouthers, R. & Gale, G.A. (2018) Utilization of waterholes by globally threatened species in deciduous dipterocarp forest of the Eastern Plains Landscape of Cambodia. *Oryx*. DOI 10.1017/S0030605318000455

Keo O. (2008) *Ecology and conservation of giant ibis in Cambodia*. PhD thesis, University of East Anglia, UK.

Miles, L., Newton, A.C., DeFries, R.S., Ravilious, C., May, I., Blyth, S., Kapos, V. & Gordon, J.E. (2006) A global overview of the conservation status of tropical dry forests. *Journal of Biogeography*, **33**, 491–505.

R Core Team (2018) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Ripple, W.J., Newsome, T.M., Wolf, C., Dirzo, R., Everatt, K.T., Galetti, M., Hayward, M.W., Kerley, G.I., Levi, T., Lindsey, P.A. & Macdonald, D.W. (2015) Collapse of the world's largest herbivores. *Science Advances*, **1**, p.e1400103.

Souter, N.J., Simpson, V., Mould, A., Eames, J.C., Gray, T.N.E, Sinclair, R., Farrell, T., Jurgens, J.A. & Billingsley, A. (2016) Will the recent changes in protected area management and the creation of five new protected areas improve biodiversity conservation in Cambodia? *Cambodian Journal of Natural History*, **2016**, 1–5.

Thuon T. & Chambers, M. (2006) *Situation Analysis: Stung Treng Province, Cambodia*. Mekong Wetlands Biodiversity Conservation and Sustainable Use Programme, Vientiane, Laos.

Tordoff, A.W., Baltzer, M.C., Fellowes, J.R., Pilgrim, J.D. & Langhammer, P.F. (2012) Key biodiversity areas in the Indo-Burma Hotspot: process, progress and future directions. *Journal of Threatened Taxa*, **4**, 2779–2787.

Ty S., Yav N., Eames, J.C., Sum P., Hong L., Thi S., Bou V. & Loveridge R. (2016) The first population census of the Critically Endangered giant ibis in Western Siem Pang, northeastern Cambodia. *Cambodian Journal of Natural History*, **2016**, 51–59.

Wharton, C.H. (1968) Man, fire and wild cattle in Southeast Asia. *Proceedings of the Annual Tall Timbers Fire Ecology Conference*, **8**, 7–167.

Wright, H.L., Buckingham, D.L. & Dolman, P.M. (2010) Dry season habitat use by critically endangered white-shouldered ibis in northern Cambodia. *Animal Conservation*, **13**, 71–79.

Wright, H.L., Collar, N.J., Lake, I.R., Bou V. & Dolman, P.M. (2012) Foraging ecology of sympatric white-shouldered ibis *Pseudibis davisoni* and giant ibis *Thaumatibis gigantea* in northern Cambodia. *Forktail*, **28**, 93–100.

Wright, H.L., Collar, N.J., Lake, I.R. & Dolman, P.M. (2013) Amphibian concentrations in desiccating mud may determine the breeding season of the white-shouldered ibis (*Pseudibis davisoni*). *The Auk*, **130**, 774–783.

Appendix 1 Size of waterholes between treatments in Western Siem Pang Wildlife Sanctuary

Treatment	*n*	Mean ± SD (m^2)	Range (m^2)
Control	10	4,111 ± 7,628	408 – 25,507
High intensity grazing	4	4,932 ± 4,377	1,837 – 8,027
Low intensity grazing	4	1,833 ± 1,482	563 – 4,558

Appendix 2 Monthly composition of waterhole microhabitats across the three treatments in Western Siem Pang Wildlife Sanctuary

Values given are mean (± SD)

Variable	Month	Control	High intensity grazing	Low intensity grazing
Water (%)	Nov	78.4 (21.4)	77.8 (15.6)	84.4 (17.8)
	Dec	46.4 (32.5)	46.3 (27.9)	58.6 (33)
	Jan	23.3 (24.4)	21.8 (18)	36.1 (30.1)
	Feb	8.4 (12.2)	9.0 (10.7)	22.3 (25.3)
	Mar	5.88 (9.98)	5.28 (9.5)	20.4 (22.4)
	Apr	8.08 (13.7)	19.5 (22.6)	11.7 (14.4)
Saturated mud (%)	Nov	8 (11.8)	8.2 (7.1)	6.7 (5.8)
	Dec	5.7 (4.6)	6.7 (4.9)	5.9 (5.2)
	Jan	3.2 (4.6)	3.6 (3.6)	6.4 (6)
	Feb	3.5 (7.6)	3.7 (5.8)	3.7 (4.0)
	Mar	4.4 (8.4)	3.1 (5.9)	5.5 (4.9)
	Apr	1.67 (2.98)	4.87 (5.69)	3.67 (4.42)
Wet mud (%)	Nov	2.85 (3.85)	4.48 (7.95)	4.6 (7.25)
	Dec	6.5 (5.2)	7.4 (7.5)	5.1 (4.9)
	Jan	3.21 (3.31)	3.5 (4.2)	5.1 (3.9)
	Feb	4.01 (5.89)	4.43 (4.9)	3.6 (4.5)
	Mar	2.89 (4.2)	3.06 (5.1)	3.49 (2.8)
	Apr	3.42 (4.92)	2.9 (5.8)	4.67 (4.4)
Dry mud (%)	Nov	10.7 (17)	9.6 (8.3)	4.3 (10.7)
	Dec	41.4 (36.2)	39.6 (27.2)	30.3 (34.2)
	Jan	67.7 (33.5)	71.1 (23.6)	52.4 (35.3)
	Feb	84.1 (18.3)	82.9 (15.4)	70.4 (28.4)
	Mar	86.8 (15.3)	88.6 (13.2)	70.7 (26.7)
	Apr	86.8 (20.5)	72.7 (31.5)	80 (17.9)
Vegetation height (cm)	Nov	52.3 (38.7)	56.8 (42.6)	72.5 (42.7)
	Dec	60.8 (78.8)	53.9 (62.6)	61.2 (48.2)
	Jan	50.4 (70.3)	37 (53.4)	40.8 (43.5)
	Feb	34.4 (47)	54.9 (72.7)	38.5 (36.2)
	Mar	28.2 (29)	14.7 (14.9)	33.5 (35.1)
	Apr	23.5 (24.3)	22.6 (21.9)	29.5 (27.3)

Appendix 3 Composition of waterhole microhabitats (mean ± SD) across the three treatments at the start and end of the study in Western Siem Pang Wildlife Sanctuary

Values given are mean (± SD)

Month	Treatment	Water (%)	Saturated Mud (%)	Wet Mud (%)	Dry Mud (%)	Vegetation Height (cm)
December 2014 (Month 1)	Control	66 (17)	8 (5)	5 (4)	22 (14)	34 (27)
	High intensity grazing	70 (10)	16 (6)	3 (0.2)	11 (4)	52 (54)
	Low intensity grazing	73 (41)	9 (4)	6 (5)	13 (16)	50 (41)
April 2017 (Month 29)	Control	16 (16)	3 (4)	7 (5)	73 (22)	21 (17)
	High intensity grazing	39 (5)	10 (2)	6 (8)	45 (2)	28 (27)
	Low intensity grazing	15 (18)	5 (2)	8 (3)	72 (20)	39 (22)

Appendix 4 Multivariate analysis of variance (MANOVA) analysis comparing final and initial microhabitat characteristics between grazed waterholes and controls in Western Siem Pang Wildlife Sanctuary

Variable	April 2017		December 2014	
	F	*p*	*F*	*p*
Area of water (%)	1.58	0.24	0.31	0.74
Area of dry mud (%)	1.87	0.19	1.10	0.36
Mean vegetation height (cm)	1.44	0.27	0.48	0.63
All three variables	1.55	0.20	1.45	0.23

Appendix 5 Number of visits to waterholes in Western Siem Pang Wildlife Sanctuary with detections of free-ranging domestic water buffalo

Treatment	Number (%) of visits with buffaloes present	Mean (range) number of buffaloes per visit	Mean herd size when buffaloes present
Control	10 (7)	0.9 (0–55)	13.6
High intensity grazing	11 (38)	4.5 (0–40)	11.9
Low intensity grazing	13 (16)	1.2 (0–17)	7.5